Detection of Male Mediterranean Fruit Flies (Diptera: Tephritidae): Performance of Trimedlure Relative to Capilure and Enriched Ginger Root Oil

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Abstract. Females of the Mediterranean fruit fly (medfly), *Ceratitis capitata* (Wiedemann), oviposit in a large number of fruits and vegetables and pose an enormous threat to agriculture worldwide. As a result, areas free of *C. capitata* often operate trapping programs to detect incipient infestations. Detection efforts rely heavily on trimedlure (TML), a male-specific attractant. Despite its wide acceptance, TML is not a particularly powerful attractant, and alternatives are being investigated. Capilure® (CPL), which contains TML plus extenders to reduce production costs and volatility, and enriched ginger root oil (EGRO), which contains the male attractant α-copaene, have been compared with TML with varying results. The present study provides additional field data comparing the effectiveness of TML against CPL or EGRO as trap baits for wild *C. ceratitis* males in a Hawaiian coffee field. While traps baited with fresh TML or CPL generally captured similar numbers of male medflies, TML-baited traps generally captured significantly more male medflies than CPL-baited traps when the lures were aged 1, 3, 8, or 10 weeks. Likewise, traps baited with fresh TML or EGRO captured equal numbers of males, whereas significantly more males were captured in TML- than EGRO-baited when the lures were aged 3 or 6 weeks. Based on these results, neither CPL nor EGRO appears an adequate substitute for TML.

Introduction

The Mediterranean fruit fly (medfly), *Ceratitis capitata* (Wiedemann), is an important agricultural pest worldwide (White and Elson-Harris 1992). Females oviposit in a wide variety of fruits and vegetables and thus pose a serious risk to commercial agriculture both in terms of crop damage and potential quarantine restrictions to international trade. As a result, areas free of *C. capitata* often operate trapping programs to detect incipient infestations (e.g., Gonzalez and Truncoso 2007, Jessup et al. 2007). Early detection is essential, because it allows both the delimitation of the outbreak and the implementation of control and eradication measures while the pest population is still small. A rapid response not only limits crop damage but also reduces the programmatic costs incurred in the eradication effort (Lance and Gates 1994, Papadopoulos et al. 2001).

Fruit fly detection programs typically rely on traps baited with food attractants or male lures. Regarding the latter, trimedlure (hereafter referred to as TML) is now the standard male medfly attractant in USA detection programs and is deployed in solid dispensers (polymeric plugs) containing 2 g of the lure (and no toxicant) that are placed in Jackson traps, which in turn are suspended within the canopy of host trees (IAEA 2003). As recommended (IAEA 2003), the TML plugs are replaced at 6-week intervals. Despite its wide

acceptance, TML is not a particularly powerful attractant, especially compared with methyl eugenol, the male lure used to detect infestations of *Bactrocera dorsalis* (Hendel), which is another serious tephritid pest (Jang and Light 1996).

The need for a more effective male medfly lure has focused attention on several alternatives. Ceralure, an iodinated analogue of TML, was shown to be 4-9 times as attractive to male medflies as TML (Jang et al. 2003, 2005), but its synthesis on a commercial scale is not yet cost effective (Jang et al. 2010). As TML is itself fairly expensive to produce and also quite volatile, another product (Capilure®, hereafter referred to as CPL) that replaces a portion of TML with proprietary extenders that reduce evaporation (Leonhardt et al. 1984, King and Landolt 1984) was developed in the early 1980s and is currently used for *Ceratitis* detection in South Africa (T.G. Grout, pers. comm.). Field tests (Nakagawa et al. 1981, Rice et al. 1984, Hill 1987, Baker et al. 1988) confirm that CPL is more persistent than TML and attracts male medflies (albeit in reduced numbers) as long as 10–36 weeks after deployment. However, these same studies have reported inconsistent results regarding the relative performance of the two lures in the initial weeks after deployment, with several studies (Hill 1987, Nakagawa et al. 1981, Rice et al. 1984) finding equivalence between TML and CPL but one (Baker et al. 1988) finding TML outperformed CPL in the 8 weeks immediately following field deployment.

In addition to these TML-based alternatives, enriched ginger root oil (*Zingiber officinale* L., hereafter referred to as EGRO), which contains α-copaene, a powerful attractant to male medflies (Flath 1994a, b), is also under study. However, the few available data are inconsistent. In Hawaii, Shelly and Pahio (2002) found TML-baited traps captured significantly more *C. capitata* males than EGRO-baited traps, whereas Mwatawala et al. (2012) recently reported similar performance of EGRO and TML in capturing male medflies in Tanzania. Moreover, these authors reported that EGRO was more effective than TML in attracting males of two congeneric species, *C. rosa* Karsch and *C. cosyra* (Walker).

The purpose of the present study was to provide additional field data comparing the effectiveness of TML against CPL or EGRO as trap baits for wild *C. capitata* males. Regarding CPL, attention was directed to relative performance in the first 10 weeks of field trapping, since (i) even in the face of budget cuts, USA domestic fruit fly surveillance programs are unlikely to adopt a lure replacement cycle substantially longer than current practice (6 weeks) regardless of the lure used and (ii) inferior performance of CPL during the initial 10 weeks would—regardless of its relative performance beyond this period—greatly reduce, and likely eliminate, any chance that it would replace TML as a tool for medfly detection in the USA .

Materials and Methods

Field work was conducted in a commercial coffee field (*Coffea arabica* L., ≈ 65 ha, 100 m elevation) in north central Oahu ≈ 10 km southeast of Haleiwa. Plant rows were spaced 3 m apart, and individual plants were maintained at a height of 2–3 m. During the study period, daily maximum and minimum air temperatures ranged from 23–28°C and 15–19°C, respectively (Haleiwa readings, weather.com).

In all tests, the standard procedure for TML deployment was followed: I used polymeric plugs containing 2 g of TML (Scentry Biologicals Inc., Billings, MT). For CPL, I also used plugs, but in this case the 2 g of materials contained approximately 65% (1.3 g) TML and 35% propri-

etary extenders (International Pheromone Systems, Ellesmere Port, UK). Plastic packets containing liquid EGRO (2 ml each) were obtained from Insect Science (Pty.) Ltd., Tzaneen, South Africa and supplied to our laboratory by S. Quilici (CIRAD, France). Through a steam distillation process, the concentration of α-copaene was increased from 0.4% in commercial ginger root oil to 8% in the EGRO (Shelly and Pahio 2002). None of the lures contained toxicant. Jackson traps (IAEA 2003) were used exclusively in the study. The TML and CPL plugs were placed in the perforated basket suspended inside the trap, and EGRO was applied to a cotton wick, which, in turn, was placed in the perforated basket within the trap.

Three replicates were conducted comparing trap catch of TML- versus CPL-baited traps in different parts of the coffee field during 2012 (Replicate 1: March 6–May 17; Replicate 2: March 20–May 31; Replicate 3: September 4-November 15). In each replicate, we placed 4 TML-baited traps and 4 CPL-baited traps in each of 5 rows (i.e., N = 20 traps total per lure). Traps were placed 1–2 m above ground within the canopy of the coffee plants. Within each row, the 2 lure types were alternated, and adjacent traps were separated by 25 m. Adjacent rows containing traps were separated by 9 intervening rows (i.e., by approximately 30 m). Traps were placed in the field at 0900–1000 hrs, operated for a 2-day interval, and then returned to the laboratory. The sticky inserts were removed, the captured flies were counted, and the traps, with lure but without the sticky insert, were suspended outdoors in a shaded location 2.0–2.5 m above ground. Traps (with fresh sticky inserts) were placed in the field when lures were fresh or aged 1, 2, 3, 8, or 10 weeks.

Owing to a limited supply of EGRO, the comparison between TML and EGRO was based on a single replicate conducted in the same manner outlined above, except the traps were placed in the field when lures were fresh or aged 3 or 6 weeks (July 10–Aug 23).

Data for each replicate were analyzed separately, because spatiotemporal variation in the size of the wild population was not monitored, and hence the degree to which this variation affected trap captures in different sites and times was unknown. For all tests, the raw data ($x + 1$) were $\log_{10}$ transformed and then used in a 2-way ANOVA with lure type and time as the main effects. In all cases, however, the interaction term was found to be significant, indicating that the effect of lure type on captures was not consistent across release dates. As a result, the main effects could not be interpreted independently, and consequently we present the results of pair wise comparisons within a particular lure age interval based on the Tukey HSD test.

Results

Results were consistent among the 3 replicates comparing TML- versus CPL-baited traps (Fig. 1). In all cases, significantly more *C. capitata* males were captured in TML- than CPL-baited traps when lures were aged 1, 2, 3, or 8 weeks. For fresh lures, there was no significance difference in captures between the TML and CPL lures in two of the replicates, while in the other replicate (#1) TML baits resulted in significantly higher trap captures than CPL baits. For lures aged 10 weeks, there was no significance difference in captures between the TML and CPL lures in one replicate (#1), while in the other two replicates the TML baits resulted in significantly higher trap captures than the CPL baits.

In the TML-EGRO trial, there was no significant difference in the number of male medflies captured in TML- versus EGRO-baited traps when the lures were

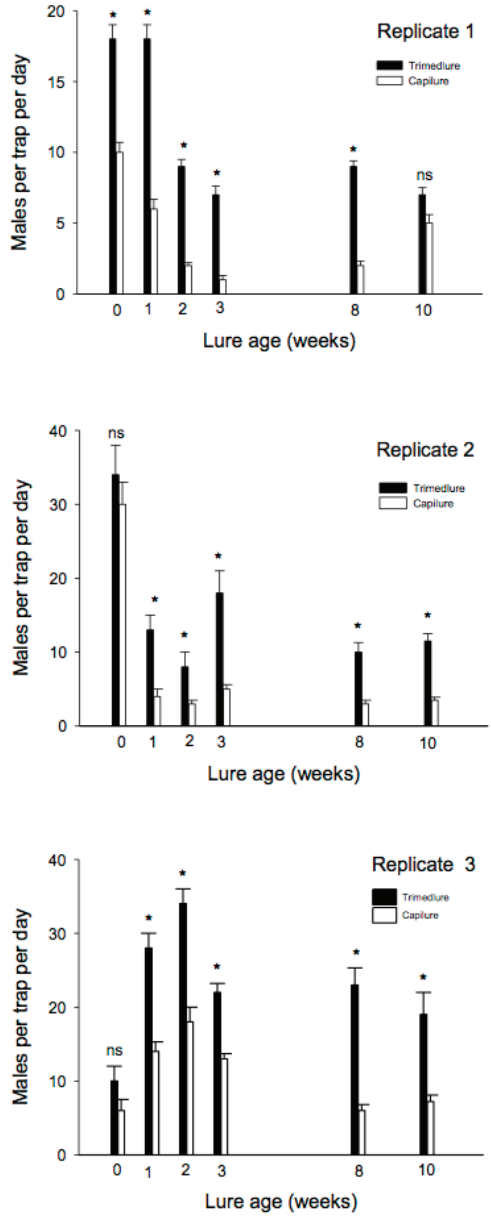

Figure 1. Capture of *C. capitata* males in TML- versus CPL-baited Jackson traps for 3 replicates in an Oahu coffee field. Abscissa represents period of lure ageing, where 0 weeks represents fresh lures. Bar heights indicate mean of 20 traps per lure type; error bars represent ± 1 SE. Symbols above bars show results of the Tukey HSD test comparing the 2 lures for each ageing category, where an asterisk indicates $P < 0.001$ and ns indicates no significant difference.

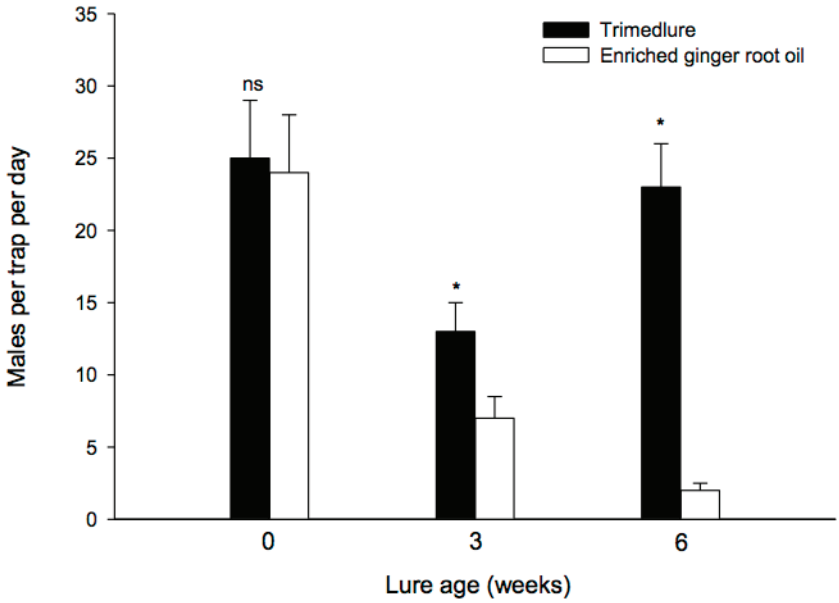

Figure 2. Capture of *C. capitata* males in TML- versus EGRO-baited Jackson traps for a single replicate in an Oahu coffee field. Abscissa represents period of lure ageing, where 0 weeks represents fresh lures. Bar heights indicate mean of 20 traps per lure type; error bars represent ± 1 SE. Symbols above bars show results of the Tukey HSD test comparing the 2 lures for each ageing category, where an asterisk indicates $P < 0.001$ and ns indicates no significant difference.

fresh, but significantly greater numbers of males were captured in TML-baited traps for lures aged 3 or 6 weeks (Fig. 2).

Discussion

The TML-CPL comparison revealed that, when lures were fresh, the two lures generally (2 of 3 replicates) resulted in similar trap captures of *C. ceratitis* males. However, for lures aged 1, 2, 3, or 8 weeks, the TML-baited traps captured significantly more males than CPL-baited traps in all 3 replicates. For lures aged 10 weeks, the TML-baited traps likewise captured more medfly males than CPL-baited traps (2 of 3 replicates).

The present findings differ from most previously published studies (Hill 1987, Nakagawa et al. 1981, Rice et al. 1984), which report similar captures in TML- and CPL-baited traps for lures aged 0–8 weeks. This discrepancy could simply reflect differences in the amount of TML used in TML versus CPL dispensers, but unfortunately these earlier studies typically did not provide the actual dose of TML contained in CPL dispensers. The superior performance of TML in weeks 1–8 in the present study is consistent with Baker et al.'s (1988) observation that, after the initial 2 weeks of weathering, TML-baited traps captured more male medflies than CPL-baited traps over weeks 3–8. Although atypical, this result was not especially surprising given the intended function of the extenders in CPL, which is to reduce the volatility of TML, which in turn likely reduces its attractiveness

(Baker et al. 1988). Moreover, owing to the addition of extenders, the amount of TML in CPL plugs tested here was only 65% that for the TML plugs, which could have reduced attractancy.

More unexpected was the finding that TML-baited traps outperformed CPL-baited traps (2 of 3 replicates) for lures aged 10 weeks. Previous measurements with 10-week aged lures have either noted similar captures between TML- and CPL-baited traps (Rice et al. 1984, Hill 1987) or significantly greater captures by CPL-baited traps (Nakagawa et al. 1981). It is possible that, had trials been extended for longer periods, CPL would have displayed more persistent attractiveness than TML. For example, Hill (1987) found that CPL-baited traps did not exhibit superiority over TML-baited traps until baits had been in the field for 12 weeks. However, even if such persistence had been observed in the present study, the finding that TML-baited traps captured significantly more *C. capitata* males during weeks 1–8 would render any long-term persistence a moot point. Even with reduced budgets, it is unlikely that USA detection programs will increase the TML replacement cycle at all or much beyond the current 6-week interval. In short, our data suggest TML is equivalent or superior to CPL for as long as 10 weeks after deployment. Although untested in the present study, if CPL outperforms TML after > 10 weeks of ageing, it may be suitable in countries where lure replacement occurs less frequently than in USA domestic programs.

The single replicate comparing TML and EGRO revealed that, while trap captures were similar for fresh lures, TML-baited traps caught significantly more *C. capitata* males than EGRO-baited traps when lures were aged 3 or 6 weeks. In another field study conducted in Hawaii, Shelly and Pahio (2002) released males in the center of a circular array of traps and reported higher catch in TML- than EGRO-baited traps when lures were fresh or aged 5 days. In contrast, tests (Mwatawala et al. 2012) conducted in Africa showed that EGRO attracted equal or greater number of males of several *Ceratitis* species (including *C. capitata*) as did TML and even attracted some species (e.g., *C. cosyra*) not usually found in TML-baited traps. The discrepancy did not appear to reflect differences in the lure or its application: the EGRO used in Hawaii was obtained from the same source and was applied in the same dose as that used in Tanzania (S. Quilici, pers. comm.). Likewise, Mwatawala et al. (2012) used standard 2 g plugs of trimedlure as was the case in Hawaii. With respect to the medfly, reasons for the differing results in Hawaii and Africa are presently unknown.

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